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Bycatch of high sea longline fisheries and measures taken by Taiwan: Actions and challenges

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ABSTRACT

Taiwan is a major longline fishing nation with an interest in proactive conservation measures. Facing global concerns about the incidental catch in longline fisheries, Taiwan has focused on bycatch issues since the 2000s. This paper reviews the existing information on bycatch and the actions taken by Taiwan in the past ten years, including the establishment of observer programs, education and outreach, adoption of national plans of action and publicizing regulations for mitigation measures. This review suggests that continuing and improving the observer program, ensuring the compliance of mitigation measures, and encouraging information exchange and international cooperation will contribute to the conservation of non-commercial species of concern.

1. Introduction

Commercial fish harvest is often accompanied by the incidental catch or killing of non-commercial species, known as bycatch [1,2]. Such non-commercial species include marine mammals, sharks, seabirds, sea turtles and other ecologically related species [3–7]. Longline fishery bycatch of seabirds and sea turtles has become a major focus [8,9]. At least 61 species of seabirds have been identified in longline bycatch [10]. Of these, 22 species are classified as endangered by the International Union for Conservation of Nature (IUCN) [11]. The delayed maturity and low fecundity of albatross (Family Diomedeidae) have received the most attention. Among 21 species of albatross in the world, 19 are listed as endangered [12]. There are only three species in the North Pacific Ocean, and the rest live at southern latitudes [13]. Research has suggested that the use of bird-scaring lines, night setting, weighted lines and other measures can prevent seabird bycatch [14–22].

There are seven species of sea turtles in the world, all of which, except the flatback turtle (*Natator depressus*), are currently considered as endangered or critically endangered on a global level according to the Red List 2008 [23]. Leatherback sea turtle (*Dermochelys coriacea*) is at risk of longline bycatch [9,24]. Methods for avoiding sea turtle bycatch and reducing mortality include time/area closure, safe de-hooking practices and circle hooks [25–27]. In comparison, cetaceans are less affected by longline fisheries, but caused catch depredation [28,29]. Studies have shown that acoustic pingers can drive off dolphins [30–32]. Several shark species are affected by bycatch, especially some of the sharks that are target species. Ecological risk analyses have identified some species as endangered [33]. Research and development of mitigation measures have been initiated in response to these findings [34–36].

For the sake of these bycatch species, the United Nations' Food and Agriculture Organization (FAO) has adopted an International Plan of Action (IPOA) to avoid seabird bycatch by longline fisheries [37], an IPOA for conservation of sharks [38] and Guidelines for sea turtle conservation [39]. Many Regional Fisheries Management Organizations (RFMOs) have adopted measures requesting or encouraging members to take actions to reduce bycatch [40,41]. Many countries have taken measures to conserve bycatch species. Beginning in the 1980s, the U.S. began to pay attention to bycatch. Regulations and detailed monitoring systems have been established [42]. Australia has shown concern for cetacean bycatch since 1984 and seabird bycatch since 1990, contributing to the conservation of these species [43]. Japan, as a major fishing nation, has put a lot of effort into the development of mitigation measures [36,44]. Brazil and Uruguay have also valued the importance of the subject [45,46]. However there are still many countries with either low observer coverage or limited data collection. RFMOs must overcome the difficulties in data collection, excess fishing capacity, mortality estimation and

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harmonization of mitigation measures across the tuna RFMOs; more efforts are needed to conserve these resources [41].

Taiwan is one of the world's major longline fishing countries. Tuna longline fisheries were introduced to Taiwan in the 1960s. They flourished in the 1980s, with a range that covered three oceans [47]. However, there was limited attention on bycatch. Due to cetacean bycatch by drift nets, Australia banned Taiwan from fishing in its Exclusive Economic Zone (EEZ) in 1986 [43], and the United Nations passed Resolution 46/215 against high seas drift-nets by 1992. Because of these actions, Taiwan recognized the impact of bycatch on its fisheries. As a responsible country, Taiwan began to gather international information and conducting outreach to fishermen. Pilot observers have been sent to collect bycatch information since 1999, and a database has been established for ongoing research and monitoring. National Plans of Action (NPOAs) and management regulations have been developed, according to which fishermen are required to take mitigation measures. The aims of this paper are to (1) illustrate Taiwan's longline fishery distribution and the developing observer program; (2) summarize the bycatch research results for four major taxonomic groups: cetaceans, seabirds, sea turtles and sharks; (3) review the history and policy of Taiwan's conservation actions pertaining to ecologically related species and (4) highlight the successes and limitations of these measures, explore possible solutions and provide suggestions for other countries.

2. Taiwan's longline fisheries and observer program

2.1. Taiwan's longline fisheries

Taiwan's longline fleet can be divided into bigeye tuna (*Thunnus obesus*) fleet and albacore tuna (*T. alalunga*) fleet. Initially, albacore was the primary target species, where fishing was conducted in temperate waters with 4000 hooks per operation and an operating depth of approximately 150–200 m. The catch was sold mostly to the United States and Thailand for canning. In the 1980s, ultra-low-temperature equipment was introduced, and fishermen began to fish bigeye tuna and yellowfin tuna (*T. albacares*). Fishing for these species was mainly done in tropical waters, with 3000 hooks per operation and a relatively deep operating depth of 250–300 m. The catch was sold to Japan as sashimi. At its highest, the number of vessels reached 841 in 1990. However, 136 vessels were decommissioned after 1990, and some of the others were outfitted with updated fishing equipment. Total production from the three oceans rose to 300 thousand tons in 1993 [47,48] and reached a historically high value of 350 thousand tons in 2003. Due to FAO International Plan of Action for the management of fishing capacity [49] and the quota limitations of RFMOs for bigeye tuna, the number of large-scale longline tuna fishing vessels was reduced to 451, and the catch in 2008 was reduced to 204 thousand tons [47,48,50–52].

As for the fishing grounds, in the Pacific Ocean, the major albacore fishing grounds are 155°E–120°W/10°S–40°S and 160°E–150°W/10°N–40°N. Bigeye and yellowfin tunas are in the tropical region, mainly 160°E–115°W/15°N–25°S. In the Indian Ocean, the major albacore fishing grounds are 15°S–40°S, especially south of 25°S. Bigeye and yellowfin tunas are targeted between 15°N and 15°S. In the Atlantic Ocean, albacores are targeted in the area south of 15°S and north of 15°N, and bigeye and yellowfin tunas are fished mainly between 20°N and 20°S [53]. The distribution and effort of recent years are shown in Fig. 1.

2.2. Observer program

Observers are regarded as the most important means of collecting bycatch information [54]. Taiwan has assigned onboard observers to record bycatch since 1999 [55]. Since 2002, 5 observers have been sent to three oceans. In response to research and RFMOs requirements, the number of observers was increased to 62 in 2009. The observer program was funded by the government, rising from a cost of US$166,000 in 2002 to US$2.05 million in 2008 (Fig. 2). In 2006, the presence of observers on Atlantic bigeye tuna vessels reached 100% in accordance with ICCAT recommendation [56]. On average, the percentage of efforts monitored by observers increased from only 0.2% in 2002 to 5.3% in 2008 (Fig. 2).

The government commissioned the Overseas Fisheries Development Council of the Republic of China (OFDC) to implement the observer program. OFDC coordinated observer training in dispatching, database building and management. Three weeks of

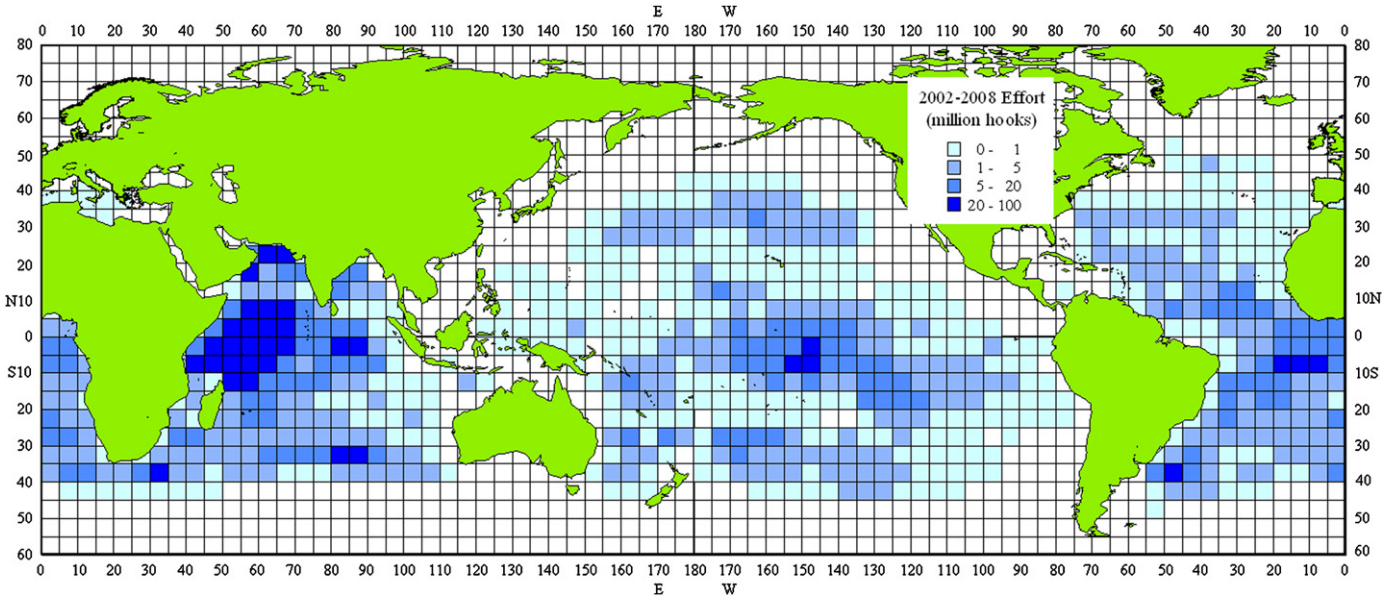

Fig. 1. Distribution of Taiwanese tuna longline fleets during 2002–2008.

training included (1) international fishery organizations and related management regulations, (2) basic fishing equipments, (3) catch records, (4) biological sampling methods and (5) safety and rescue skills. Recorded observer data included (1) operational information such as vessel name, captain name, tonnage, length and communication equipment; (2) daily operating records, including latitude and longitude, bait, number of hooks, wind speed and other environmental factors; (3) fish characteristics, including body length and weight, condition and gender; (4) bycatch characteristics, including species, amounts, status (live release or discarded) and fin–body ratio of sharks and (5) biological samples such as otoliths, stomach contents, muscles, spine and others. Each observer took 2–3 trips every year, approximately three months per trip.

Vessel sampling was based on ocean regions. Stratified sampling was performed on fleets (bigeye tuna fleet, albacore fleet and southern bluefin tuna fleet). In the beginning, having observers on board was not compulsory. Additional 20 tons bigeye tuna quota per vessel was allocated for vessels carrying observers for encouragement. After 2006, carrying observers was mandatory, and reward quotas were only given to encourage their cooperation on research projects such as circle hooks experiment. In addition, the government announced that the captain and crews must accommodate the needs of observers, including the use of communication equipments, access to the deck and assistance with taking specimen.

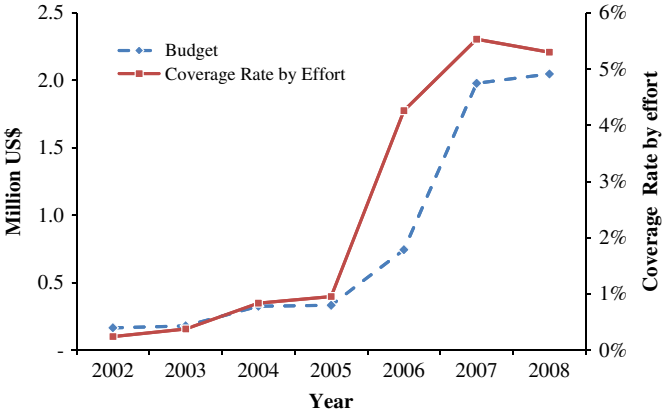

Fig. 2. Budget and observer coverage rate by effort of Taiwanese longline fisheries from 2002 to 2008.

3. Research on ecologically related species

3.1. Bycatch research before implementing observer program

In 1990, Taiwan was criticized for the catch of dolphins in Penghu [57,58]. This criticism inspired Taiwan to conduct research on cetacean conservation and to investigate bycatch of species along the coast, the amount of each species involved, the possible causes and to estimate the Taiwanese coastal gillnet bycatch of cetaceans [59–61]. For distant water fisheries, the known cetacean depredation rate in the Indian Ocean was as high as 30–60% [59]. However, questionnaires were the only source of information for this research, and the sampling number was limited, resulting in a high degree of uncertainty.

Research on sea turtles began in the 1990s, focusing on a survey of green turtle (*Chelonia mydas*) habitat in Wangan, Pehgu, Taiwan. The protection area for sea turtles was drawn [62,63].

Because sharks were the target species of Taiwan's coastal fisheries, biological samples could be obtained more easily. Therefore, a greater number of studies were done on shark stocks along Taiwan's coast and the North Pacific Ocean [64–69].

Research on bycatch of seabirds was conducted by an interview of captains from Cape Town, South Africa, who indirectly understood the impact of seabird bycatch in Taiwan's longline tuna fisheries [70].

3.2. Bycatch research after implementing observer program

Based on the data collected by observer from 2002 to 2008, the observed areas covered most of the fishing ground (Fig. 3). Analysis of the bycatch follows.

3.2.1. Seabirds

There were at least 32 species of seabirds recorded in the Pacific Ocean, including 14 species in the North Pacific Ocean, 9 species in tropical waters and 9 species in the South Pacific Ocean. The bycatch rate was about 0–0.65 per 1000 hooks with an

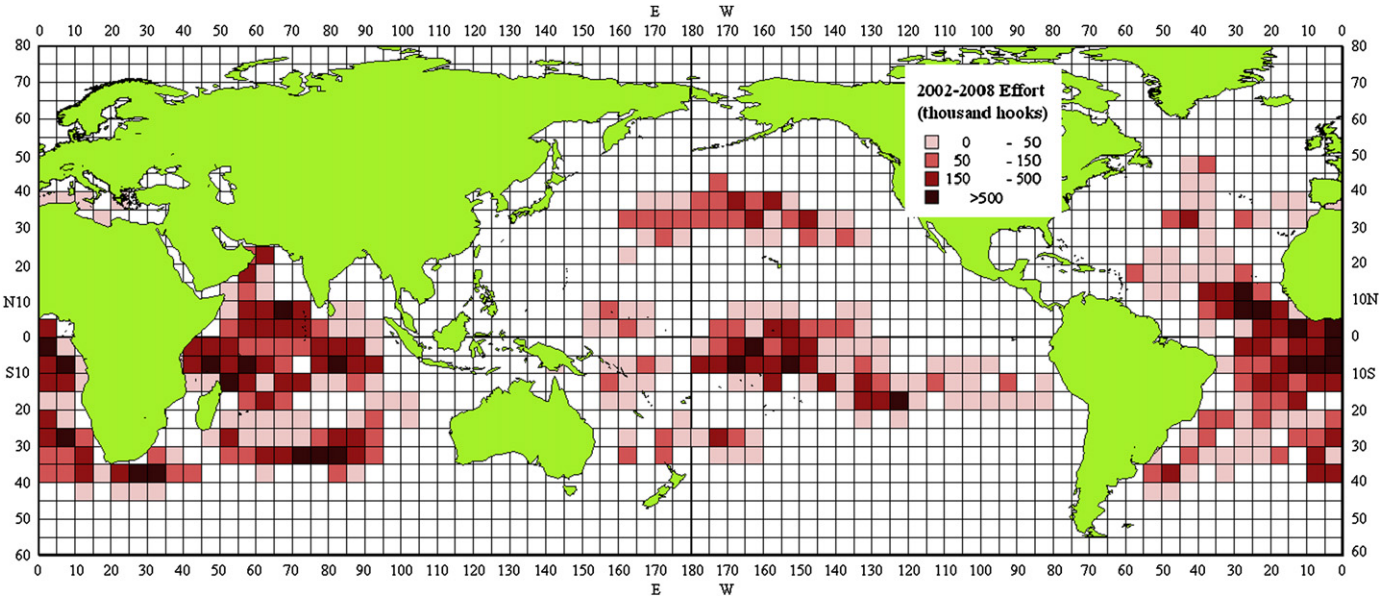

Fig. 3. Distribution of Taiwanese observed effort during 2002–2008.

average bycatch per unit effort (BPUE) of 0.045 per 1000 hooks from 2002 to 2006. The incidental catch was the highest in the areas between 25–40°N and 165°W–165°E and areas between 25–35°S and 165–180°W. Black-footed albatross (*Phoebastria nigripes*) and Laysan albatross (*Phoebastria immutabilis*) were affected by bycatch. The preliminary estimated annual seabird incidental catch was approximately 1700 from 2002 to 2006 [71].

Indian Ocean recorded species included 33 seabirds, with 6 species affected by bycatch, mainly distributed in the area of 29–32°S and 70–90°E. The main bycatch species included Indian yellow-nosed albatross (*Thalassarche carteri*), sooty albatross (*Phoebetria fusca*), wandering albatross (*Diomedea exulans*) and Salvin's albatross (*Thalassarche salvini*). The bycatch rates were 0.0002 per 1000 hooks in tropical areas and 0.0158 per 1000 hooks in the southern Indian Ocean in 2004–2008. It was estimated that 311–715 seabirds were incidentally caught annually in 2004 and 2008 [72].

A total of 28 seabird species were recorded in the Atlantic Ocean, including 2 species in the northern latitudes, 15 species in tropical waters and 12 species in southern latitudes [73]. Bycatch was mainly distributed in the Southeast Atlantic Ocean and Southwest Atlantic Ocean (35–45°S/35–45°W and 30–40°S/5–15°W, respectively), with a bycatch rate of 0–0.2266 per 1000 hooks in the period of 2004–2008. The estimated number of seabirds affected by bycatch was about 900 each year. The bycatch species included wandering albatross, yellow-nosed albatross, black-browed albatross (*Thalassarche melanophrys*), sooty albatross, giant petrels and cape petrel [74].

Overall, seabirds observed in tropical waters included booby, noddy, shearwater and frigatebirds. These were mostly small- and medium-sized seabirds that did not follow the fishing vessels for food [75,76], and most of them were the species of least ecological concern [77]. Less effort was made and fewer observational records were obtained in the North Atlantic Ocean and the South Pacific Ocean, and more data are needed in these areas. The North Pacific Ocean and the South Atlantic Ocean were considered to have relatively high bycatch rates, and mitigation measures should be strengthened and ensured in these areas.

3.2.2. Sea turtles

Pacific and Indian Ocean sea turtle bycatch was concentrated in tropical waters, while the bycatch in Atlantic waters was more broadly distributed. Species recorded in the Pacific Ocean included olive ridley (*Lepidochelys olivacea*), leatherback, green turtle and loggerhead turtle (Caretta caretta). A bycatch of 82 sea turtles was recorded in 2002–2006, mainly at 0–10°N and 130–150°W. The bycatch rate was 0.015 per 1000 hooks [78].

Five sea turtle species were recorded in the Indian Ocean, with bycatch mainly distributed at 10°N–7°S by 48–90°E. The bycatch species included olive ridley, leatherback, loggerhead and green turtles. The bycatch rates were 0.000 in the southern areas and 0.0112 per 1000 hooks in the tropical Indian Ocean in the period of 2004–2008. It was estimated that 1127–1856 turtles were incidentally caught annually in 2004 and 2008 [72].

Six species of sea turtles were observed in the tropical waters of the Atlantic Ocean, and these species were found at lower latitudes. The bycatch rate at high latitudes in 2007 was 0.0004–0.0027 per 1000 hooks, compared to 0.0145 per 1000 hooks in tropical regions [79].

3.2.3. Cetaceans

Cetaceans were observed frequently in the tropical regions. At least three species were recorded in the tropical and temperate waters of the Pacific Ocean [78]. Eight cetaceans were recorded in the Atlantic Ocean, of which the pan-tropical spotted dolphin (*Stenella attenuata*) and bottlenose dolphin (*Tursiops truncatus*) were seen most frequently [73]. Seven species were recorded in the Indian Ocean, where the bigeye tuna fleet experienced depredation rate of up to 12.3%, which led to higher bigeye tuna discard rate [72]. Cetacean bycatch was rare. There was one bycatch in the Atlantic Ocean in 2007 [79].

3.2.4. Sharks

The annual production of sharks in Taiwan was 39,000–55,000 tons. Of these, 85% were caught in distant water fisheries, in which blue shark (*Prionace glauca*) was the main species caught, accounting for approximately 70–80%. Other species included silky shark (*Carcharhinus falciformis*), thresher sharks, hammerhead sharks, shortfin mako sharks (*Isurus oxyrinchus*) and others [80].

There were 8 bycatch shark species in the Atlantic Ocean, mainly blue shark, bigeye thresher shark (*Alopias superciliosus*) and mako shark [56,79]. Blue shark accounted for 3.8% (in the south albacore fleet) to 18.1% (in the bigeye tuna fleet), with an average of 12.0%. The nominal catch per unit effort (CPUE) was estimated to be 1.378 and 0.444 per 1000 hooks in tropical and southern areas, respectively [55]

At least ten bycatch shark species were recorded in the Indian Ocean, accounting for 4.4% of all fish in number, including 2.0% blue shark, followed by the silky shark, shortfin mako and bigeye thresher. Of bycatch sharks, 54.2% was released live or discarded. The sharks captured by different vessels ranged from 1.0% to 3.8% of total catch in number [72].

Pacific Ocean blue shark bycatch accounted for 2.1% of the number of catch, ranging from 0.7% in the southern albacore fleet to 3.4% in the bigeye tuna fleet, followed by silky shark bycatch. A larger distribution of bycatch among species was seen in tropical areas [78].

According to different bycatch rates found in the waters of the three oceans, the estimated annual weight of the shark bycatch ranged from 4000 to 15,000 tons in the Atlantic Ocean, from 2000 to 13,000 tons in the Pacific Ocean and from 730 to 9957 tons in the Indian Ocean from 2002 to 2008 [81].

3.3. Mitigation measures research

To reduce the bycatch of ecologically related species by tuna fishing vessels, the effectiveness of circle hooks and pingers was explored. In 2006, circle hook research was conducted on six Atlantic fishing vessels and two Pacific fishing vessels; test results show that more fish were captured with the circle hooks in Atlantic fishing vessels, while a higher capture was found with J-hooks in the Pacific fishing vessels. However, the difference was not significant. No significant difference was seen between the use of J-hooks and circle hooks for sea turtle bycatch [82].

In response to frequent depredation by cetaceans [72], a test was conducted in 2005 on the fishing vessels of the South Pacific and Indian Oceans where 10 kHz fixed-frequency acoustic pingers or 5–160 kHz random frequency small pingers were affixed to longlines. The results indicated that the 10 kHz pinger had the deterrent effect, which could reduce the amount of line snapping caused by cetaceans [83].

4. Policy and actions

4.1. Education and outreach

Taiwan has collected international information since the late 1990s, translated and compiled into teaching materials and distributed to captains, crews, fishing companies and fishermen groups to promote mitigation measures. In 1996, Taiwan was authorized by the Australia Tasmania Park to reprint the publication "Catch fish, not the bird" (in Chinese). In 2000, it produced

"catch fish, but not catch birds – which led to the coexistence of fisheries and seabirds peacefully" brochure. Cartoons were used in propaganda to teach common bycatch mitigation measures. Beginning in 2000, seabird bycatch mitigation measures have been included in crew training courses. In 2003, Birdlife International's "Avoid catching and safely release seabirds" posters were distributed. In 2004, a Chinese version of the "seabird conservation booklet" was produced through a collaboration with the convention for the Conservation of Southern Bluefin Tuna (CCSBT). In 2005, a guide to identification of sea turtle species and safe procedures for freeing hooked turtles were printed.

Workshops and conferences were held to strengthen stakeholder participation and to raise public awareness. In 2002, an international information exchange and discussion was held in Taiwan, together with WildAid, at the International Shark Conservation Conference. Domestic fishermen and foreign scholars were invited to exchange views. In 2004, Taiwan hosted a workshop with Birdlife International on mitigation measures for avoiding bycatch of seabirds. Taiwan had participated in the International Fishers Forum for 4 times, beginning with its first year in 2000. The government also organized the Fifth International Fishers Forum with the United States in August 2010.

The government has also participated in related international meetings, including the ecosystem/bycatch sub-committee meetings of the ICCAT, International Scientific Committee (ISC), Inter-American Tropical Tuna Commission (IATTC), Western and Central Pacific Fisheries Commission (WCPFC), Commission for the Conservation of Southern Bluefin Tuna (CCSBT) and Convention on the International Trade in Endangered Species (CITES).

4.2. National plans of action

The seabird and shark IPOAs recommended that all related nations develop NPOAs to find solutions to bycatch [37,38]. With the size of Taiwan's tuna fishing vessels under consideration, and thorough review of the seabird and shark bycatch, Taiwan's seabird NPOA and shark NPOA were adopted in 2005 and 2006.

According to the seabird NPOA, considering RFMO recommendations, conservation seabird species list, the distribution of Taiwan's tuna fishing vessels overlapped with the waters where seabirds were concentrated, the seabirds bycatch conditions in different waters have been continuously collected. Measures have been taken, evaluation systems established and continuous promotion and training have been conducted [84].

The shark NPOA reviewed the shark bycatch in Taiwan distant water fisheries and coastal fisheries, logbook records, landings, sampling vessel records, observers and other means were used to estimate the catch of sharks. Regional cooperation, education, information exchange and other measures have been taken and a management system for sharks has been established [80].

4.3. Legislation for the mitigation of bycatch

Learning from previous lessons on high seas drift-net prohibitions, and as a WCPFC, IATTC member, CCSBT extended commission member and ICCAT cooperating non-member, Taiwan has obligations to implement RFMOs conservation measures. All related regulations are listed in Table 1.

Among four taxonomic groups, cetaceans' bycatch rate in longline operations was the lowest, but it received the highest rank attention in regulation. In response to international conservation efforts, Taiwan developed the Wildlife Conservation Act in 1989, in which a variety of cetaceans were listed as endangered species. Criminal penalty was imposed if there were illegal catch or retention. The law successfully reduced fishing for these species along the coast, particularly in bycatch of cetaceans with drift nets.

For other species, since 2003, Taiwan has added the requirement of reporting the catch of blue shark, mako shark, silky shark and other sharks to strengthen data collection. Since 2005, longline fishing vessels were required to be equipped with line cutter, de-hookers, hand dip nets and other equipments for the release of incidentally captured seabirds and sea turtles. When fishing vessels accidentally catch sea turtles, seabirds, sharks and cetaceans, the live individuals must be released, the dead ones discarded and the amount to be reported in the logbook.

Since 2005, finning of sharks has been forbidden in the Atlantic and Indian oceans, followed in the Pacific Ocean since 2006. When sharks are transported at sea and into port, the shark fins to body weight ratio should not exceed 5%. Living sharks must be released and recorded in the logbook, and shark fin ratios must be confirmed when catch is brought back to Taiwan for sale. Since 2007, when fishing vessels enter foreign ports, the weights of shark fins and shark bodies must be declared, and a document issued by the port government must be obtained. In light of the provisions of the Indian Ocean Tuna Commission (IOTC), fishing vessels in the Indian Oceans are prohibited from retaining on board, transshipping, landing, storing, selling or offering for sale any part or whole carcass of Thresher Sharks (Family Alopiidae) since 2010. If any of them are caught accidentally, they must be returned to the sea and reported as part of the discarded in the logbook. In response to the ICCAT recommendations, beginning in 2010, bigeye thresher sharks (*Alopias superciliosus*) must be released or discarded. Beginning in 2011, oceanic whitetip sharks (*Carcharhinus longimanus*) and hammerhead sharks of the Family Sphyrnidae (except for the *Sphyrna tiburo*) are prohibited from retaining on board.

Beginning in 2005, fishing vessels catching southern bluefin tuna (*T. maccoyii*) must be equipped with two bird-scaring lines (tori lines) while fishing in the three oceans in areas south of 30°S. Beginning in 2007, fishing vessels must be equipped with two bird-scaring lines while fishing in the Pacific Ocean in areas south of 30°S and north of 23°N. Four bird-scaring lines must be placed on board. Beginning in 2008, bird-scaring lines must be used when fishing in Atlantic Ocean south of 20°S and in the Indian Ocean south of 28°S. Furthermore, at least two kinds of mitigation measures must be used since 2009, including bird-scaring lines, night setting with minimum deck lighting, weighted branch lines, blue dye squid bait, offal discharge control and line shooting device in compliance with the IOTC Resolution of 08/03. In addition, the regulated area is extended to the 25° of south in the Indian Ocean since 2010. The fishing vessels should provide evidence of the purchase of bird-scaring lines, including photographs.

Beginning in 2009, if fishing vessels operating in Pacific Ocean find the sea turtles to be comatose or inactive, they must be taken on board to foster their recovery and released back into the sea. If sea turtles are accidentally entangled in purse seiners or fish aggregating devices (FAD), all appropriate measures must be taken to release the sea turtles safely.

4.4. Private sector efforts

Conservation measures are influenced by non-governmental organizations (NGOs) [43]. In Taiwan, NGOs participate primarily in cetacean and seabird conservation. The Taiwan Cetacean Society was established in 1998, the first cetacean conservation association in Asia. Conferences are held every year, focusing on cetacean conservation, including bycatch issues [85]. The Chinese Wild Bird Society is closely associated with Birdlife International. Relevant meetings are attended occasionally. In 2005, the society

Table 1
Legislation of mitigation of ecological related bycatch species.

Taxa	Year enacted	Oceans	Official law (date adopted and code)	Note
Cetacean	1989	All	Wildlife Conservation Act (1989.6.23. Code 3266)	Twenty-seven species are listed on the conservation appendix
Seabirds, sea turtles, sharks	2005	Three	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in three oceans (2005.2.5. Code 0941330124)	De-hookers and dip nets on board, live release
Sharks	2005	Atlantic	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Atlantic Ocean of 2005 (2005.2.5. Code 0941330127)	Prohibition of shark finning
	2005	Indian	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Indian Ocean of 2005 (2005.2.5. Code 0941330126)	Prohibition of shark finning
	2006	Pacific	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Pacific Ocean of 2006 (2006.3.30. Code 0951330540)	Prohibition of shark finning
	2007	Atlantic	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Atlantic Ocean of 2007 (2007.1.16. Code 0961330021)	Port states documentations for sharks landing
		Pacific	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Pacific Ocean of 2007 (2007.3.28. Code 0961330634)	Port states documentations for sharks landing
		Indian	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Indian Ocean of 2007 (2007.3.2. Code 0961330515)	Port states documentations for sharks landing
	2010	Indian	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Atlantic Ocean of 2010 (2010.1.21. Code 0991330000)	Prohibition of thresher sharks retaining on board
	2010	Atlantic	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Atlantic Ocean of 2010 (2009.12.16. Code 0981332510)	Prohibition of bigeye thresher sharks retaining on board
	2011	Atlantic	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Atlantic Ocean of 2011 (2011.1.12. Code 0991331818)	Prohibition of oceanic whitetip sharks and hammerhead sharks retaining on board
Seabirds	2005	Three	Regulations for fishing vessels catching southern bluefin tuna in three oceans of 2004 (2003.11.28. Code 0921331476)	Tori lines for vessels operating in South of 30°S.
	2007	Pacific	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Pacific Ocean of 2007 (2007.3.28. Code 0961330634)	Mitigation measures in areas south of 30°S and north of 23°N
	2008	Atlantic	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Atlantic Ocean of 2008 (2008.2.1. Code 0971330185)	Mitigation measures in south of 20°S
	2008	Indian	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Indian Ocean of 2008 (2008.2.25. Code 0971330020)	Mitigation measures in south of 28°S
	2009	Indian	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Indian Ocean of 2009 (2009.2.13. Code 0981330064)	Multimitigation measures in south of 28°S
	2010	Indian	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Indian Ocean of 2010 (2010.1.21. Code 0991330000)	Multimitigation measures in south of 25°S
Sea turtles	2009	Pacific	Regulations for fishing vessels over 100 gross registered tonnages catching tunas and tuna-like species in the Pacific Ocean of 2009 (2009.3.12. Code 0981330302)	Safety release

Note:

1. All regulations are announced by Council of Agriculture. The Wildlife Conservation Act is announced by Bureau of Forestry, and the others are announced by Fisheries Agency.
2. All of those fisheries operation regulations are amended annually, the first ones are listed in this table to record the beginning year.
3. Wildlife Animal Act (in English) could be found at http://conservation.forest.gov.tw/ct.asp?xItem=21726&ctNode=193&mp=10. The others could be found at http://www.fa.gov.tw/laws/list.aspx?Node=480&Index=2&Code=6030 (in Chinese).

went to Mauritius' Port Louis to educate the Taiwanese crews of fishing vessels on seabird mitigation measures. The Taiwan Tuna Association has cooperated with the government to promote educational programs to the industry and to cooperate with the Organization for the Promotion of Responsible Tuna Fisheries (OPRT). These organizations have printed seabird conservation posters and distributed them to members to teach the need for seabird protection.

5. Challenges and possible resolutions

Implementation of observer programs and mitigation measures is a key to bycatch research and conservation. In recent years, Taiwan has increased manpower and funding for the establishment of high seas tuna fishery observer programs and extensive collection of bycatch information and analysis. However, in the case of increasing demand for international

standards and research, this system can still be strengthened as follows.

5.1. Sampling of observer program and enhanced data quality

The key to a successful observer program is proper coverage rate. RFMOs set observer coverage standards at 5–10% [41]. For the target species with a high encounter rate, 1% might be sufficient [86]. For species with a low encounter rate, coverage of 20% or more is needed [87,88]. The funding for the observer program is limited, causing difficulty in improving observer coverage [89]. The encounter rate and the bycatch rate should be coordinated with ecological risk analyses to prioritize species to stratify sampling. With an average bycatch rate of 5%, sending an increased number of observers to bycatch hotspots can improve data reliability.

In addition, to improve bycatch data quality such as seabird species identification, abundance, mortality and length-quality judgments, a seabird species identification system can be created through video or high resolution photos.

5.2. Improvement and enforcement of mitigation measures

Current estimations of the bycatch rate of Taiwanese vessels are mostly derived from information gathered prior to the implementation of mitigation measures. Since 2007, Taiwan has taken a number of mitigation measures. Through regular monitoring, it is hoped that bycatch rates can be effectively reduced. Continuing to collect and analyzing the effectiveness of mitigation measures are important to find the best resolution for reducing bycatch.

However, the effectiveness of mitigation measures may be varied by fleets. The Agreement for the Conservation of Albatrosses and Petrels (ACAP) inspected various mitigation measures, and suggested that multiple measures should be applied [21]. Japanese studies have shown that increasing the weight of ropes may cause harm to crews. Circle hooks have had different effects in different fisheries [90]. Therefore, continuation of data collection of mitigation measures among different fisheries should be considered.

Monitoring of fishing operations is difficult because the fishing vessels operate at the high sea. Fishermen have been asked to provide receipt of purchase of equipment and photos as evidence of implementation of mitigation techniques. On-board observers will also record the presence of mitigation equipment. In addition, port measures are powerful tools. One Taiwanese fishing vessel has been fined for shark finning and banned from operating by the Taiwanese government for three months along with withdrawal of the captain's license for one year. Such measures will underscore to fishermen the seriousness of illegal actions.

5.3. International cooperation framework

From the perspective of ecosystem management, fisheries as well as seabirds, sea turtles, sharks and cetaceans are parts of the marine environment. The main aim of RFMOs is to reduce fisheries bycatch. Information from one nation is not enough to understand the entire picture. Therefore, international cooperation is important [40,91]. Bycatch data integration and analysis must be strengthened. Many related countries have no bycatch-associated observer program. Some Tuna RFMOs lack dedicated personnel, who must consult external experts. For both research needs and data confidentiality, RFMOs should hire permanent staff and periodically exchange information with related organizations such as ACAP, IUCN and Birdlife International. Global bycatch and biological databases should be established by the appropriate authorities, and the information should be shared by nations and scholars to help conserve marine life. The FISHBASE and Biological Diversity websites are useful examples.

6. Conclusion

Taiwan developed its distant water fisheries for over sixty years. In the 1990s, after facing the prohibition against high sea drift net from the United Nations for conservation of bycatch species, Taiwan understood the importance of bycatch conservation. Taiwan made efforts to conduct related research and mitigation measures to fulfill its responsibility as a member of RFMOs. First, Taiwan collected information to educate fishermen taking actions to avoid bycatch. Second, Taiwan established high sea fisheries observer program to collect information to provide important information for tuna longline fisheries. The annual observed sets exceeded 7000 in 2008. Third, fishermen were requested to use mitigation measures to meet the international organization standards. In the future, Taiwan will continue to improve these programs and strengthen international cooperation. These experiences lay the foundation for international cooperation and set an example for those countries that are not implementing mitigation measures yet.

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